

CONF. 780580-1

GEOTHERMAL WELL TECHNOLOGY PROGRAM*

S. G. Varnado
Sandia Laboratories
Albuquerque, New Mexico 87185

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Abstract

The high cost of drilling and completing geothermal wells is an impediment to the development of geothermal energy resources. Technological deficiencies in rotary drilling techniques are evidenced when drilling geothermal wells. The Division of Geothermal Energy (DGE) of the U. S. Department of Energy has initiated a program aimed at developing new drilling and completion techniques for geothermal wells. The goals of this program are to reduce well costs by 25% by 1982 and by 50% by 1986. Sandia Laboratories has been selected to manage this technology development program, and this paper presents an overview of the program. Program justification which relates well cost to busbar energy cost and to DGE power-on-line goals is presented. Technological deficiencies encountered when current rotary drilling techniques are used for geothermal wells are discussed. A program for correcting these deficiencies is described.

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Introduction

The Division of Geothermal Energy (DGE) of the U. S. Department of Energy (DOE) has established geothermal power-on-line goals of 3,000 MW_e by 1985 and 20,000 MW_e by the year 2000¹ for the National Geothermal Energy Program. Achievement of these goals will be possible only if geothermal energy competes on a favorable economic basis with energy from conventional sources, e.g., fossil and nuclear. The cost of drilling and completing geothermal wells accounts for a significant portion of the cost of geothermally produced power. At the present time, the cost per foot of geothermal wells is about two to four times that of conventional oil and gas wells²⁻⁴ (see Figure 1), and these costs must be reduced if DGE power-on-line goals are to be met.

Reductions in well cost will result in reduced busbar energy cost for geothermally-produced electricity. This will, in turn, improve the relative economic position of geothermal power in the market-place and will lead to substitution of geothermal power for conventional power. For example, Bloomster⁵ has

* Work supported by the U. S. Department of Energy

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estimated that a 6% reduction in geothermal busbar energy cost would lead to a 13% increase in geothermal power-on-line, and that reductions of 10 to 35% in busbar cost would effectively double the amount of geothermal energy that is economically attractive because large, lower temperature reserves become competitive. Therefore, the critical questions concerning geothermal drilling and completion technology development relate to the impact of well cost on busbar energy cost and to the effectiveness of technological improvements in reducing well costs.

Figure 2 indicates the sensitivity of busbar energy costs to well cost and reservoir temperature.² Assuming a base cost of \$500,000 per well, a 40% reduction in well cost, for example, would result in a decrease in busbar energy cost of from 15 to 23%, depending on reservoir temperature. Since geothermal power-on-line is sensitive to busbar energy cost, reductions in well cost have the potential for significantly accelerating the utilization of geothermal energy. Therefore, it is important to consider the role of technology development in reducing well cost.

Present Difficulties in Drilling

The high cost associated with geothermal wells is due in part to a number of deficiencies in geothermal drilling and completion technology. These deficiencies are attributable to temperature, formation, and corrosion and erosion effects which are found uniquely or primarily in geothermal environments.

Temperature Effects -- The high temperature environment encountered in geothermal wells produces adverse effects on drilling fluids, casing and cement, bits, and elastomeric materials.

Drilling-fluid-related difficulties form the single most frequently cited category of geothermal drilling problems. Lost circulation is a pervasive difficulty in the geothermal field because of the highly fractured formations in which geothermal resources are found. Fluids which remain stable at high temperature often do not have adequate filtration characteristics for control or lost circulation. Furthermore, conventional muds tend to gel when circulation is stopped for tripping, logging, and running casing. This can lead to induced problems such as stuck tools and failures of the drill string from differential sticking. Expensive procedures are required to correct these fluid-related failures.

Drilling fluids can also affect the quality of the cementing job, since they tend to contaminate the cement, and muds that have

gelled and thickened leave excessive filter cake on the casing and formation. This filter cake inhibits good cement bonding. Also, a thickened mud can cause the cement to channel behind the casing and can result in large uncemented regions. These regions can fill with water which can vaporize at geothermal temperatures. The pressures which build up have the potential for causing collapse of the casing.

A further problem results from uncertainty in determining the temperature profile of the well. Geothermal cements must be formulated with the proper amount of retardants. Incorrect mixtures will fail to set up properly and may lead to expensive remedial cementing ("perf and squeeze"). Such operations are expensive in themselves and also increase non-rotating rig costs.

The predominant mode of bit failure in geothermal wells is through bearing failure. Unsealed bearings are normally used because elastomeric seals will not survive the high temperatures encountered. The bearings and races are lubricated only by the drilling fluid. High downhole temperature and increased friction cause these critical parts to experience much higher temperatures than the main bit body. Examination⁶ of bits used at the Geysers, where formation temperatures are about 240°C, has shown that temperatures up to 540°C are experienced at the friction pin, and that significant softening of the steel occurs at 260-316°C. The high temperature and resultant softening of the bearing surfaces reduces bit life at the Geysers to 1/4-1/5 normal. Costs are increased by the need for more bits, the greater number of round trips required, and reduced penetration rates while drilling.

Currently, the best available elastomers fail at temperatures of 175-225°C depending upon use and environment. These materials cease to be elastomeric when subjected to high temperatures and pressures, and thus their value in geothermal applications is limited. Unfortunately, elastomers are important to virtually every aspect of drilling. Current designs of rock bits, downhole motors, blowout preventers, packers, and logging tools all contain elastomers. Most of this equipment either cannot be used or can be used only with frequent, costly inspection, repair, and special procedures.

Formation Effects -- In addition to the extra costs due to high temperature, additional costs are often incurred in geothermal drilling because of the type and condition of the formations which must be penetrated. The fractured formations that predominate in most geothermal reservoirs (except the geopressured Gulf Coast) cause severe stresses on drilling equipment. Furthermore, many reservoirs exist in hard or medium-hard formations where penetration is slow and equipment wear is high.

Erosion and Corrosion Effects -- Air is an attractive fluid for drilling into competent reservoirs because it will not damage the formations and generally improves rate of penetration. However, air drilling causes rapid erosion of downhole equipment.⁷ At the Geysers, where the drill string is frequently inspected and hardbanded and where a special anti-erosion additive is used in the air stream, it is still necessary to junk one foot of drill pipe for each seven feet of hole.⁸ These procedures require extra services and additional training for the rig crew, and the high discard rate for pipe requires advance planning to insure adequate supplies of replacements.

Completion problems can arise for those wells which produce wet stream because it can erode casing as the high speed fluid strips water film from the casing surface. Higher quality casing with flush joints must be used to reduce the problem.

When hot, acidic brines or H₂S are present, downhole equipment is subject to embrittlement and corrosion. These conditions also require special procedures and training for the crews. Also, more expensive, corrosion resistant materials are used, and additives may be required in the drilling fluid to help control corrosion.

Geothermal Well Technology Development Program

In view of the existing technological difficulties associated with drilling and completing geothermal wells, DOE/DGE has initiated a program directed at developing and commercializing the technology required to reduce the cost of geothermal wells. An analysis of existing geothermal well cost data indicates that technological developments such as higher penetration rate, longer life rock bits; high temperature drilling fluids; improved completion techniques; and improved directional drilling techniques have the potential for reducing the cost of geothermal wells drilled with conventional rotary technology by approximately 25%. Cost reductions in excess of 25% will require the use of new drilling techniques. Research in novel drilling techniques is presently underway, and the successful implementation of these new techniques could possibly reduce well costs by as much as 50%. Based on these facts, cost reduction goals of 25% by 1982 and 50% by 1986 have been set for the DOE/DGE Geothermal Well Technology Program.

In October of 1977, Sandia Laboratories was selected by DOE/DGE to manage the well technology development program. Since that time a detailed, ten-year program plan has been prepared, and technical management of contracted R&D activities has begun. In addition, in-house research is being conducted on novel bit designs, high temperature elastomers, and novel drilling systems.

Drilling technology R&D efforts during 1978 are centered on three major areas: high temperature downhole motors, high performance rock bits, and high temperature drilling fluids. Completion technology efforts emphasize sand control methods in geopressured formations and analyses of reinjection well plugging problems in all reservoirs.

Bearings and Seals -- Sandia is presently funding work at Terra Tek directed at the development of high temperature bearings, seals, and lubricants for use in bits and downhole motors. Under previous DOE funding, a seal tester has been developed and is available for general use. Temperatures and pressures representative of geothermal well borehole conditions can be simulated in this tester. In addition, a twenty-five-foot-long borehole simulator suitable for testing the bearing and seal package for a geothermal downhole motor has been constructed. Extension of this simulator to allow full scale motor testing is underway.

Bit Development -- Bit development includes investigation of sealed and unsealed geothermal bits at Terra Tek, of water jet erosion drilling at the University of Missouri, of cavitation assisted diamond bits at Hydronautics, of Stratapax^R bits at General Electric, and of the continuous chain, downhole replaceable bit at Sandia. These efforts are directed at increasing penetration rate and bit life in the geothermal environment.

Drilling Fluid Development -- The development of high temperature drilling fluids is of critical importance to achieving the cost reduction goals of this program. Of primary concern are problems with lost circulation, well control, and formation damage. Fluid problems vary with the type of geothermal reservoir, e.g., liquid vs. vapor dominated, and a range of fluids must be developed, and a range of fluids must be developed to satisfy the different drilling requirements.

Research in high temperature drilling fluids is underway under DOE funding at Maurer Engineering, Baroid, and the University of Oklahoma. Maurer has performed high temperature laboratory tests of commercially available muds, and is presently involved in a study of high temperature drilling foams. Baroid has entered a cost sharing contract with DOE/DGE to design, fabricate, and test a 700°F, 20,000 psi mud flow loop to test

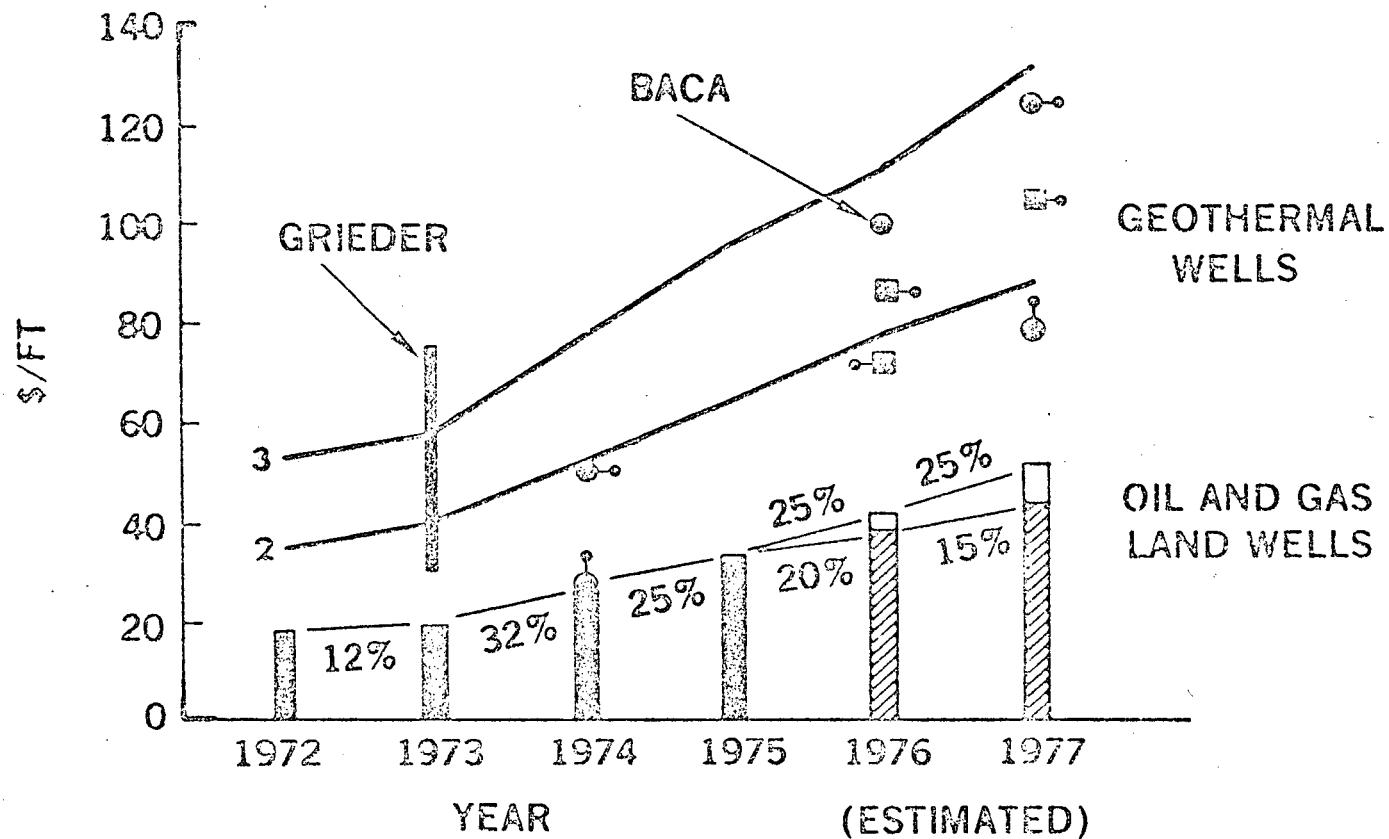
^R Registered trademark for the General Electric synthetic diamond cutters

rheology, filtration, density, and corrosion characteristics of muds at temperature and pressure. The University of Oklahoma is using a modified Magcoabar mud flow loop for testing muds to 400°F.

Additional work will be funded both at universities and in private industry. In general, competitive solicitations will be offered to involve as many participants as possible. It is recognized that the question of patent rights is a major impediment to active industrial participation in the DOE/Sandia technology development program. Industry is reluctant to accept Government funds for development work if their competitive position might be jeopardized by public disclosure of research results. In some cases, it may be necessary to grant exclusive patent rights to participating companies. Contractual arrangements which allow private industry to participate in joint research programs while not compromising their competitive position will be sought. This strategy is necessary to encourage commercialization of new technology.

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LEGEND

→ GEYSERS, CA

○ - AVERAGE

— RAFT RIVER #3, ID

■ - ACTUAL WELL

↑ IMPERIAL VALLEY, CA

Figure 1. Trend in footage costs for geothermal wells as compared to oil and gas land wells

RECENT ESTIMATES OF THE IMPACT
OF REDUCTIONS IN WELL COST
BATTELLE NORTHWEST, 1976

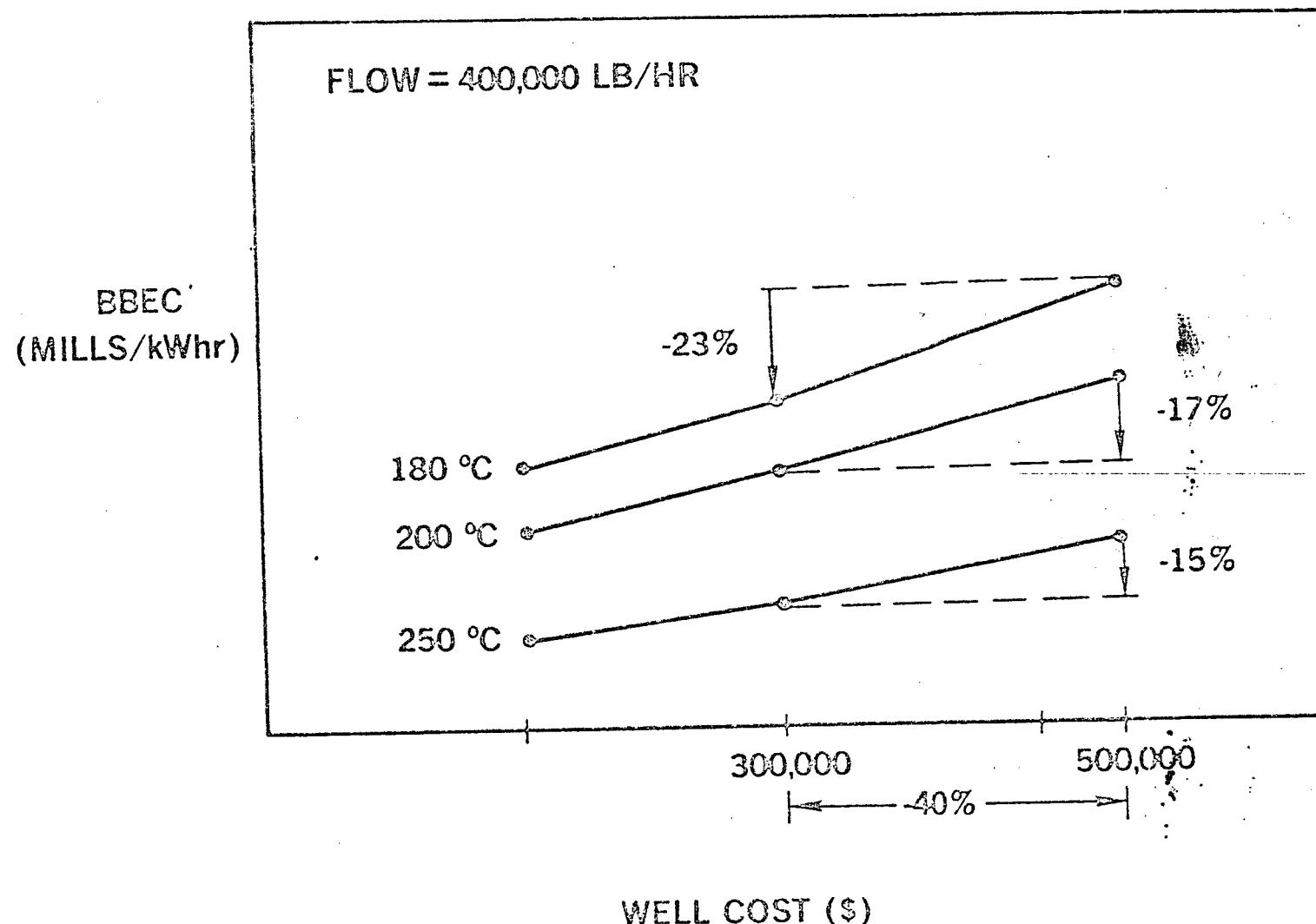


Figure 2. Recent estimates of the impact of reductions in well cost